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Impact of Preceding Crop and Cultural Practices on Rye Growth in Winter Wheat

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Improving crop vigor can suppress growth of weeds present in the crop. This study examined the impact of preceding crop and cultural practices on rye growth in winter wheat. Preceding crops were soybean, spring wheat, and an oat/dry pea mixture. Two cultural treatments in winter wheat were also compared, referred to as conventional and competitive canopies. The competitive canopy differed from the conventional in that the seeding rate was 67% higher and starter fertilizer was banded with the seed. The study was conducted at Brookings, SD. Rye seed and biomass production differed fourfold among treatments, with winter wheat following oat/pea being most suppressive of rye growth. Rye produced 63 seeds/plant in winter wheat with a competitive canopy that followed oat/pea, contrasting with 273 seeds/plant in conventional winter wheat following spring wheat. Yield loss in winter wheat due to rye interference increased with rye biomass, but winter wheat was more tolerant of rye interference following oat/pea compared with the other preceding crops. Regression analysis indicated that winter wheat yield loss at the same rye biomass was threefold higher following spring wheat or soybean compared with oat/pea as a preceding crop. Winter wheat competitiveness and tolerance to rye can be improved by increasing the seeding rate, using a starter fertilizer, and growing winter wheat after an oat/pea mixture.

Nomenclature: Dry pea, *Pisum sativum* L.; oat, *Avena sativa* L.; rye, *Secale cereale* L.; soybean, *Glycine max* (L.) Merr.; wheat, *Triticum aestivum* L.

Key words: Population dynamics, seed production, synergism, systems design.

Producers in the western Corn Belt are fortunate to have a wide arsenal of herbicides to control weeds. However, weed resistance and concerns about herbicide impact on human health and the environment are stimulating questions about the extensive reliance on herbicides (Miller 2008). A further issue is the rising cost of inputs for crop production (Anderson et al. 2006). Thus, producers are interested in production systems that are not so dependent on herbicides for weed management.

An alternative to herbicide-based management is the population-based approach, where cropping systems are designed to suppress weed population growth (Bastiaans et al. 2000; Mortensen et al. 2000). The benefit of this approach can be substantial; producers in the Central Great Plains using this approach reduced cost of weed management 50% compared with conventional practices (Anderson 2005). Management includes cultural tactics that reduce seedbank density, suppress weed seedling emergence in the crop, and minimize seed production of weeds escaping control tactics. Herbicides are not needed in some crops because weed community density is so low. The population-based approach is also successfully managing weeds in winter wheat regions of Australia (Jones and Medd 2000).

A key to successful population-based management in the Central Great Plains is rotations comprised of crops with different life cycles, such as winter wheat and corn (*Zea mays* L.)(Anderson 2004). Differences in life cycles provide more opportunities for producers to control seedlings of weeds with contrasting life cycles to the current crop. Therefore, we are examining the inclusion of cool-season crops such as winter wheat in the corn–soybean rotation in eastern South Dakota. Our first study examined winter wheat productivity; winter wheat yielded almost 5,000 kg/ha following an oat/pea mixture harvested for hay (Anderson 2008a). A following study found that weeds common in corn and soybean, such as common lambsquarters (*Chenopodium album* L.) and foxtail species (*Setaria* spp.), were not able to establish and produce seeds in winter wheat (Anderson 2008b). Thus, winter wheat can disrupt population dynamics of these weeds.

Producers may plant winter wheat after soybean to expand the corn–soybean rotation. However, normal harvesting dates for soybean will result in winter wheat being planted 2 to 3 wk later than normal, which may affect its productivity. When we evaluated winter wheat production following oat/pea, we also compared soybean as a preceding crop (Anderson 2008a). Winter wheat not only yielded 12% less following soybean compared with oat/pea, but its development was also delayed by the later planting date. Light penetration to the soil surface in early May was twofold higher in winter wheat following soybean compared with oat/pea, which may reduce winter wheat competitiveness with weeds. This delayed development with winter wheat may not be favorable for population-based weed management, as minimizing weed seed production in the crop was essential for success with this approach in the Central Great Plains (Anderson 2005). We are especially concerned with winter annual weeds such as feral rye, which is prominent in winter wheat throughout South Dakota (Western Coordinating Committee [WCC] 2009), and also grown as a cover crop in eastern South Dakota. Rye productivity is affected by cultural practices in winter wheat, varying almost 50% among canopy treatments with winter wheat in the Central Great Plains (Anderson 1997).

Producers are asking for information about alternative crops and their placement in the corn–soybean rotation. The objective of this experiment was to assess impact of preceding crop and cultural practices on winter wheat competitiveness with rye. Our broader goal is to understand aspects of weed population dynamics as affected by crop diversity, and

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subsequently, develop a population-based approach to weed management for the corn–soybean rotation.

Materials and Methods

Site Characteristics. The study was established on a Barnes clay loam (Calcic Hapludoll) near Brookings, SD, during 2005 to 2007. The soil contained approximately 3% organic matter and soil pH ranged from 6.8 to 7.2. Average annual precipitation (84-yr record) is 537 mm, with May and June receiving the greatest rainfall. The study sites were established in a field with a cropping history of corn–soybean that had been no-till for the previous 4 yr.

Treatments and Data Collection. Six treatments, consisting of three preceding crops and two management systems in winter wheat, were established in a 2-yr interval. The preceding crops, soybean, oat/pea mixture, and spring wheat, were established with no-till in corn stubble and harvested in the first year. Winter wheat was planted in the fall of the first year, and harvested in the second year. The experimental design was a 3 by 2 factorial, with the six treatments randomized in a complete block; treatments were replicated four times. Plot size was 7 by 7 m. The study was conducted at two sites with the same soil type; the first study was conducted during 2005 and 2006, and the second study occurred during 2006 to 2007.

Spring wheat 'Russ' was planted at 129 kg/ha, whereas the oat/pea mixture, consisting of 2:1 mixture of Austrian winter pea and 'Jerry' oats, was planted at 166 kg/ha. These crops were planted between April 3 and 7 with both studies. Soybean, 'Stine 099', was planted between May 15 and 20, with a target population of 400,000 seeds/ha. For spring wheat, N as ammonium nitrate was broadcast at 95 kg N/ha when plants were tillering. A starter fertilizer of 40 kg P/ha plus 15 kg K/ha was applied between the seed rows of soybean at planting. No fertilizer was applied to the oat/pea mixture. Both soybean and pea were inoculated with rhizobium. Weeds were controlled with bromoxynil at 0.4 kg ai/ha in spring wheat and with glyphosate at 0.8 kg ae/ha in soybean; weeds did not establish in the oat/pea mixture. Oat/pea was harvested as a hay crop in late July. Spring wheat and soybean were harvested for grain in early August or October, respectively.

Winter wheat was established with no-till in the residue of the three preceding crops. Winter wheat 'Harding' was planted September 12, 2005, and September 10, 2006 into oat/pea and spring wheat residue, whereas winter wheat was planted on October 1 into soybean stubble on the day of harvest in both years. Two canopy treatments for winter wheat, conventional or competitive, were also compared. The conventional treatment consisted of a seeding rate of 1.8 million seeds/ha with granular N fertilizer broadcast in the spring when plants were tillering. The competitive canopy consisted of a seeding rate of 3 million seeds/ha with N fertilizer applied at two times, a starter fertilizer at planting and a broadcast application at tillering. Nitrogen fertilizer rates were based on a yield goal of 5,000 kg/ha and adjusted for preceding crop (Gerwing and Gelderman 2002). The N rate applied to winter wheat was 130, 140, and 150 kg/ha following soybean, oat/pea, and spring wheat, respectively. The starter fertilizer consisted of 15 kg N/ha + 18 kg P/ha banded with the seed in the furrow. A low density of broadleaf weeds (< 1 plant/10 m^2) infested winter wheat in the first study and was controlled with bromoxynil at 0.4 kg/ha applied in early May of 2005. All crops were planted with a double disk drill in rows spaced 19 cm apart.

A land race variety of rye was established in a 1 by 2 m quadrat, 3 d after winter wheat had emerged. Rye at 17 seeds/m^2 was planted by hand between wheat rows and 30 cm apart within the interrow area; approximately 90% of the seeds produced seedlings, resulting in 15.4 ± 0.6 plants/m^2 averaged across all quadrats. In both years, soil moisture after planting was favorable for germination, and rye establishment did not vary among treatments. One week before wheat harvest, all rye plants were harvested by hand to determine biomass and seed number per plant. Plant density was recorded, samples weighed after drying in a forced air oven at 40 C for 5 d, and then threshed with a stationary thresher.[1] Seed number was determined by weighing the grain sample, counting seeds in 10% of the sample, and then multiplying the number of seeds by 10. Data for each sample were divided by the number of plants in that sample to express data on a plant basis.

Winter wheat grain yield was determined from the rye-infested quadrat as well as an adjacent rye-free quadrat of the same size; the rye-free quadrat was located in the same planted rows as the rye quadrat with a separation of 40 cm between quadrats. The hand samples were threshed with a stationary thresher.[1] Yield loss due to rye interference was calculated by comparing sample weights between the rye-infested and rye-free quadrats for each plot and expressed as a percentage of rye-free yield.

Statistical Analysis. Data were analyzed as a two-way factorial arranged in a randomized complete block design; preceding crop and canopy development were the two factors. Data were initially examined for homogeneity of variance[2] among years, and then subjected to analysis of variance to determine treatments effects and possible interactions among treatments and years. Main and interaction effects were considered significant at $P \leq 0.05$; treatment means were separated with Fisher's Protected LSD (0.05).

A regression analysis[3] was conducted to relate percent yield loss with total rye biomass present in the rye-infested quadrat for each preceding crop treatment. Data were pooled across canopies in winter wheat and years for each preceding crop treatment.

Results and Discussion

Statistical analysis with wheat yield and rye production data indicated that an interaction between treatments and years did not occur; therefore, data were pooled across years. However, interactions occurred between preceding crop and canopy treatments with all agronomic parameters; thus, data are presented for all treatments.

Rye Growth as Affected by Preceding Crop and Canopy Competitiveness. Rye seed production varied as much as fourfold among treatments, ranging from 63 seeds/plant in competitive winter wheat following oat/pea to 273 seeds/plant in conventional winter wheat following spring

Table 1. Biomass of rye and winter wheat yield as affected by preceding crop or canopy treatment in winter wheat. A competitive canopy in winter wheat included a higher seeding rate (50% above the conventional canopy) and banding a starter fertilizer with the seed. Data pooled across years.[a]

	Rye seed production		Rye biomass		Winter wheat yield	
Preceding crop	Competitive	Conventional	Competitive	Conventional	Competitive	Conventional
	No./plant		g/plant		kg/ha	
Oat/pea	68 a	142 b	5.5 a	9.4 b	4,850 a	4,410 b
Soybean	181 bc	223 c	9.9 b	14.2 c	4,340 bc	4,050 cd
Spring wheat	141 b	269 d	9.6 b	20.6 d	4,020 d	2,965 e

[a] Treatment means for winter wheat yield or rye seed production and biomass followed by an identical letter are not significantly different as determined by the Fisher's Protected LSD (0.05).

wheat (Table 1). Competitive winter wheat reduced the number of rye seeds/plant compared with the conventional canopy following oat/pea and spring wheat. Averaged across canopy treatments, rye produced twofold more seeds/plant in winter wheat following soybean compared with oat/pea.

Biomass of rye plants showed a similar trend among treatments as found with seed production (Table 1). Rye produced 5.5 g of biomass/plant in competitive winter wheat following oat/pea, compared to 20.6 g/plant in the conventional canopy following spring wheat. Biomass production of rye was higher in the conventional canopy compared with the competitive canopy for all preceding crops.

Winter Wheat Yield as Affected by Preceding Crop. *Weed-Free Conditions.* Winter wheat yielded the highest when oat/pea was the preceding crop (Table 1). Canopy treatments also affected yield in this sequence, as the competitive canopy increased yield 10% compared with conventional winter wheat, a gain of 440 kg/ha. Winter wheat yielded more following soybean than spring wheat with similar canopies, even though planting was delayed 2 wk when following soybean. The impact of preceding crop was especially pronounced when conventional winter wheat followed spring wheat; yield was 2965 kg/ha, or a 39% reduction compared to competitive winter wheat following oat/pea. Lower yields following spring wheat may be related to root diseases, as legumes and oat have been shown to reduce root disease severity in wheat compared to continuous wheat (Krupinsky et al. 2002).

Rye-Infested Conditions. Yield loss in winter wheat infested with rye reflected biomass levels of rye. Yield loss was 1% when winter wheat with a competitive canopy followed oat/pea, where rye produced less than 6 g/plant (Figure 1). In contrast, rye reduced yield of conventional winter wheat following spring wheat 25% when rye produced almost 21 g/plant. Yield loss due to rye interference was similar for the two canopy treatments following soybean and the competitive canopy following spring wheat. Competitive canopies reduced yield loss due to rye interference compared with the conventional canopy when oat/pea and spring wheat were preceding crops.

Oat/Pea Improves Winter Wheat Tolerance to Rye. As we examined winter wheat yield with rye interference, we noticed that yield loss when oat/pea was the preceding crop was disproportionate to biomass levels compared with the other preceding crops. For example, biomass of rye was similar in conventional winter wheat following oat/pea compared to competitive winter wheat following either soybean or spring wheat (Table 1). Yet, yield loss differed more than twofold among these three treatments (Figure 1). To examine this trend further, we developed regression lines for yield loss and total rye biomass/harvested quadrat for the three preceding crops, pooled across canopy treatments and years (Figure 2). Comparing rye at 150 g of biomass/m^2, yield loss was only 5% when winter wheat followed oat/pea, contrasting with approximately 15% yield loss when soybean or spring wheat were the preceding crops. Rye interference affected winter wheat similarly following either soybean or spring wheat.

This trend may appear to be an anomaly, but some crops improve resource-use efficiency of following crops. Dry pea increased water-use efficiency of winter wheat more than 20% compared to proso millet (*Panicum miliaceum* L.) preceding wheat (Anderson 2009), whereas corn was twofold more tolerant of a uniform infestation of weeds following dry pea compared with following soybean (Anderson 2008c). Even with weed-free conditions, corn yielded more following dry pea than soybean. We speculate that oat/pea improved resource-use efficiency of winter wheat, consequently minimizing impact of rye interference and competition for resources.

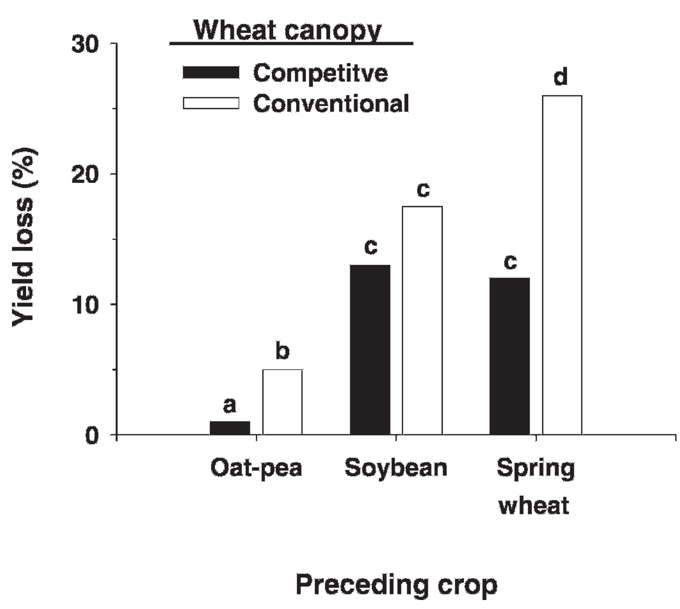

Figure 1. Yield loss in winter wheat due to rye interference, as affected by preceding crop and canopy treatment in winter wheat. Data pooled across years. Bars with identical letters are not significantly different as determined by Fisher's Protected LSD (0.05).

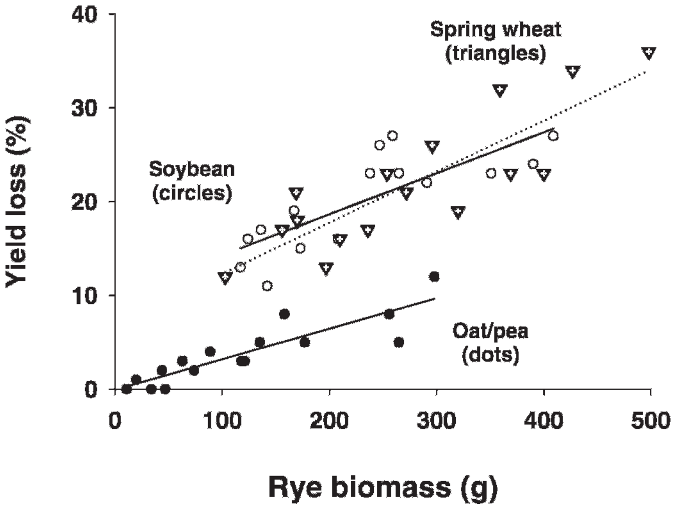

Figure 2. Impact of preceding crop on winter wheat tolerance to rye interference; data pooled across canopy treatments within preceding crop and years. Regression equation for winter wheat following spring wheat is: $Y = 6.9 + 0.054X$, $r^2 = 0.73$; following soybean, $Y = 9.9 + 0.043X$, $r^2 = 0.65$; and following oat/pea, $Y = 0.032X - 0.08$, $r^2 = 0.79$. The dotted line is the regression line for winter wheat following spring wheat.

Implications for Weed Management. A population-centered approach to weed management is successfully controlling weeds in the Central Great Plains with less cost than herbicide-based management (Anderson 2005). One component of this approach is reducing weed seed production in the crop. Our study shows the impact preceding crop and a competitive canopy in winter wheat can have on rye growth, as number of seeds/rye plant varied fourfold among treatments (Table 1).

The most favorable sequence from a weed management perspective was winter wheat following oat/pea, as rye growth was least whereas tolerance to rye interference was highest with this sequence. Producers can use a winter wheat–corn–soybean rotation; however, this sequence may not be favorable for population management as shown by the twofold difference in seed production between oat/pea and soybean as preceding crop (Figure 1). A similar rotation in the Central Great Plains, winter wheat–corn–proso millet, was not effective in reducing either weed density or weed management cost compared with herbicide-based management (Anderson 2007). Rotations most favorable for the population-centered approach in the Central Great Plains consisted of two cool-season crops followed by two warm-season crops.

A further concern with winter wheat following soybean is that warm-season weeds may be able to establish and produce seeds because of delayed development of wheat (Anderson 2008b). Our harvest date of October 1 for soybean was near the beginning of normal harvest times in this area. Later harvest of soybean will further delay winter wheat planting and subsequent canopy development, thus favoring growth of warm-season weeds in winter wheat.

Population-centered weed management may require changing the corn–soybean rotation. But producers are concerned that adding cool-season crops to the rotation will reduce net returns. A possible solution for this concern is a multifunctional approach developed in the Netherlands, where rotations are designed to maximize economic returns with several benefits because of crop diversity (Vereijken 1992). Producers were able to add small grain crops to high-value vegetable crops and maintain similar economic returns, primarily because of reduced input costs. The multifunctional approach also helped producers in the Central Great Plains change the conventional winter wheat–fallow rotation. With the use of four-crop rotations, producers increased net returns and land productivity, whereas reducing infestation levels and management costs for weeds, disease, and insects (Anderson 2009).

Adding more crops to the corn–soybean rotation will gain other benefits in addition to weed management. Crop yield increases (Katsvairo et al. 2002; Zhang et al. 1996) whereas density of the major pests, corn rootworm, and soybean cyst nematode, declines with increasing crop diversity (Levine et al. 2002; Miller et al. 2006). Economic returns are favorable with winter wheat–corn–soybean compared with corn–soybean (Meyer-Aurich et al. 2006). Adding a fourth crop may also generate favorable returns if input costs can be reduced further, especially with weed management.

Sources of Materials

[1] Stationary thresher, Kincaid Equipment Manufacturing, Haven, KS 67543.

[2] Statistix, Analytical Software, Tallahassee, FL 32317.

[3] Sigma Plot, Jandel Scientific, Point Richmond, CA 94804.

Acknowledgments

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